Policy, Planning, and Research

WORKING PAPERS

Energy Sector Management
and Assessments

Industry and Energy Department
The World Bank
November 1988
WPS 68

Domestic Lighting

Robert van der Plas

Electric lights are superior to kerosene lamps in almost all ways — they are far more energy-efficient, but their high front-end costs keep many people from enjoying their advantages.

Policy, Planning, and Research

WORKING PAPERS

Energy Sector Management and Assessments

The average amount of fuel consumed for lighting is much higher in villages without electricity than in villages with it — five times higher in Indonesia, twice as high in India. Moreover, people with kerosene lamps have much lower lighting levels than people with electric lights.

Why, then, do people still use kerosene lamps when electricity is available? Mainly because they fit well with a poor family's spending patterns. The price of a wick lamp is low. The monthly cost of using it is low. And kerosene can be bought in small quantities as needed.

But the marginal cost of adding another kerosene lamp is greater than the marginal benefit. The addition of another lamp neither increases the level of lighting nor improves the quality — but it does increase the consumption of kerosene.

People have figured this out. A survey of a few households in Rwanda and Burundi in October 1987 showed that households relying on kerosene wick lamps use only one for the whole house.

Households with electric lights are accustomed to much higher levels of light — for which they have to finance a connection charge and installation cost and for which they pay more for regular use. Such households typically have four or five lamps in the whole house and good lighting levels in each room.

The difference between kerosene and electric lamps are like those between bicycles and cars: both get you where you want to go but at certain costs with certain benefits. Although both kinds of lamps give light, they are not directly comparable because they differ so greatly in their characteristics: it takes 18 kerosene lamps to give off the light of a single 60 watt incandescent bulb.

This paper, a product of the Household Energy Unit in the Energy and Sector Management and Assessments Division, Industry and Energy Department, has also appeared as an Industry and Energy Department Working Paper. Copies are available free from the World Bank, 1818 H Street NW, Washington DC 20433. Please contact Vonica Burroughs, room S4-035, extension 33635.

TABLE OF CONTENTS

DIAGRAMS

I. BACKGROUND AND SUMMARY

Introduction

1.1 Lighting is one of the determinants of the quality of life. In most developing countries, households spend a considerable part of their cash income on modern fuels to meet their lighting needs. If households can afford electricity and if grid power is available in their houses, they use this source to meet their lighting needs. In many cases, however, people rely on petroleum products (mainly kerosene) as their principal means of lighting either because the electricity grid has not reached their area or, if it has, they have no access to it.

1.2 Despite the importance of lighting, both in terms of quality of life and cash expenditures in developing countries, little is known about:

(a) the actual amount of energy consumed for lighting;

(b) the energy efficiency of lamps; and

(c) the quality of the lighting obtained.

1.3 Factory statistics on modern electric lamps are numerous, but data on other light sources are lacking, conflicting, or of uncertain origin. In addition, no yardstick has been defined by which to measure deviations from the standard. This type of information is important, for example, for rural electrification programs, where the financial and economic analysis is partly based on the amount of fuel replaced by electricity. The absence of information on the fuel consumed or light emitted by certain lighting applications makes comparative analysis difficult and obscures the choices for providing lighting through other sources.

1.4 Surveys 1/ conducted in several countries show that the average amount of fuel consumed for lighting in non-electrified villages is much higher than in electrified villages. Moreover, these surveys also show that there are large differences in lighting energy consumption: in Indonesia it is 5 times higher in non-electrified villages than in electrified villages as measured in about 20 villages; in India it is from 1.3 to 2.7 higher as measured in about 40 villages. All these surveys do not give much information on the quality or the level of the lighting. However, observations indicate that people who use kerosene for lighting accept much lower lighting levels than people who use electricity.

1.5 One of the reasons why people still accept kerosene lighting, even though it results in extremely low lighting levels, is its attractive financial situation which is quite well adapted to a poor family's spending pattern:

(a) the purchase price of a kerosene wick lamp is low;

(b) the monthly costs for usage of the light source are low; and

(c) fuel can be bought in small quantities a few times per month as needed.

1.6 Marginal costs for expanding the existing kerosene lighting system seem to be higher than resulting marginal benefits: adding one or

---

1/ See: Household Energy Handbook; The World Bank Technical Report No. 67.

more wick lamps to the existing lamp does not frequently occur in practice: it does not result in a more acceptable lighting level nor in a more acceptable lighting quality, but it does increase the costs for lighting - and it also increases the energy consumption.

1.7 People who use electric lamps are used to much higher lighting levels than people who use kerosene wick lamps, but they:

(a) pay more to receive these lighting levels; and

(b) have to finance a (usually) high **connection charge** and a **wiring cost** before they are connected to the grid and are able to use electricity.

A micro survey conducted by one of the authors among a few households in Rwanda/Burundi in October 1987 resulted in the following observations: households depending on kerosene wick lamps for lighting use only one lamp for the whole house and obtained lighting levels that are almost unacceptable. Electricity using households use more than 4 or 5 lamps for the whole house and lighting levels are good in every single room of the house. When the differences between these two types of households are considered (although the situation is by no means representative for the city), it is found that households which use electricity for lighting:

(a) consume 1.2 times more energy (not taking into account electricity generation efficiency);

(b) pay 4 times more money (if connection and wiring costs are spread out over 25 years); and

(c) receive more than 100 times more light tnan kerosene-using households.

1.8 The difference in order of magnitude between these figures is of importance. The differences between kerosene and electricity lighting are comparable to the differences between a bicycle and a car: both provide transport, but at widely differing costs and level of comfort. Hence, although both kerosene wick lamps and electric lamps give light, they are not directly comparable since their characteristics are very different: imagine the 18 kerosene wick lamps (all in one room) required to replace one 60 W incandescent electric lamp!

1.9 To obtain a better understanding of the range of lighting conditions existing in the residential sector of developing countries (i.e. the amount of fuel consumed for lighting; the energy efficiency of lighting equipment commonly used; obtained lighting quality; available options for improvement), ESMAP 2/ commissioned tests of a number of commonly used non-electric lighting sources. 3/ The test results yielded a set of comparative data and a method of measuring these data that can be used to help analyzing financial and economic merits of rural electrification projects and household energy projects. The following chapters give an introduction to the subject of lighting, both from the (light)-technical and economic/financial point of view.

2/ The Energy Sector Management Assistance Program, a grant UNDP/World Bank Program for which the Bank is executing agency.

3/ Laboratory tests were done by Mr. A. B. de Graaff, field tests by ESMAP staff members. The report was written by Mr. R. J. van der Plas and Mr. A. B. de Graaff.

II. TEST METHODS

Lighting in Theory

2.1 Two factors that characterize lighting in a certain room are the photometric characteristics of the **luminaires** 4/ and their arrangement in that room. The resulting **luminous conditions** in that room are the total result of the quality of the lighting and the photometric characteristics of the room with its furnishings, i.e. dimensions and shape of the room, **reflectances** of its boundaries, etc. The luminous conditions of a room is a general term used for the total of the various aspects of **visibility** and visual comfort, and is usually judged by the following aspects:

(a) light level at the task area and other parts of the room;

(b) degree of glare;

(c) **color appearance** and **color rendering** of light source; and

(d) tonality of the shadows cast on objects, revelation of three-dimensional shapes, amount of veiling reflections, brightness pattern in the room, and the luminous atmosphere in general.

2.2 The quality of lighting is judged in relation to the intended activities and the environment in which these are to be performed. A

4/ Annex 1 presents a glossary of photometrical terms used and a short introduction to these terms. Photometric keywords are printed in boldface when introduced. Simplified interpretation of a few technical terms are: luminaire - lamp + fixture, etc. together as a whole; luminance - brightness of a lamp; luminous flux - light emitted by a source; illuminance - light received on a surface.

lighting system that is of good quality for circulation in an empty space with light boundaries may not necessarily be good for circulation in an untidy room with dark boundaries.

2.3 The light level is the most important factor in determining visibility of details of objects. Strictly speaking, the photometric quantity that should be used to express lighting levels is the **luminance** in the visual field of the observer. The luminance of a surface (expressed in [cd/m^2]), is the quotient of the luminous intensity reflected by that surface towards the observer's eyes and the apparent surface area. The luminance of a matt surface, apart from a factor $1/\pi$, is the product of the surface illuminance (expressed in lux, [lx] = [lm/m^2]) and the surface reflectance. For matt surfaces of average reflectance, as these usually occur in dwellings, the illuminance at the relevant surfaces can be used to express the lighting level. In terms of illuminance, the recommended lighting levels vary roughly according to the task at hand as follows:

50 - 150 lux for general residential lighting;

300 - 750 lux for desk lighting;

150 - 300 lux for auditoriums; and

300 - 500 lux for stores.

2.4 The degree of glare from the light source experienced by a user is mainly caused by the **source luminance** (the brightness of the source) in relation to other luminances present in the user's visual field. Two major types of glare are distinguished -- discomfort glare and disability glare. The first causes discomfort but does not affect visibility; the second reduces the visibility and perception of details in objects and is usually experienced from extremely bright sources near the line of sight.

2.5 The color appearance of a light source is the color emitted by that source, and may be described by its coordinates in the **CIE chromaticity diagram**, or by its **correlated color temperature** subject to its **chromaticity** being close to that of a **blackbody radiator.** Chromaticity is less important for a light source's acceptability than the **color rendering index** (CRI). Only under exceptional circumstances does the color of the light source determine its acceptability (because the user associates the color of the light with something pleasing, romantic, etc.): blue light from the sky, yellow light from a candle, red light from a sunset can be acceptable whereas green light from a pressurized kerosene lamp will never be fully acceptable. Two light sources with a similar chromaticity can have a different CRI which makes one acceptable and the other not, e.g. a low pressure sodium lamp with a low CRI can be quite acceptable for general street lighting, but is unacceptable for those applications where color perception is of importance, whereas a yellow incandescent lamp of a similar chromacity may be quite acceptable for the latter.

2.6 Other variables affecting the luminous conditions in a room are mainly caused by the directionality of the light in terms of the luminous intensities of the source. It is beyond the scope of this report to deal with these variables in any further detail.

Lighting in Practice: A Reference Standard

2.7 There is a need for a standard of comparison between different lighting options. Two obvious choices are: electric lamps or kerosene lamps. In view of the long-term solution this report has selected electricity as the standard for comparison of lighting options. In developing countries it has been observed that domestic lighting users are usually quite satisfied with a 60 Watt general service electric incandescent lamp to light their living room when electricity is first introduced. The standard for comparison used in this report therefore is the luminous conditions resulting from an appropriate luminaire with a normal 60 Watt electric incandescent lamp in the center of a room with a ceiling height of 2.5 m, a length of 5 m, and a width of 3 m. The source is assumed to be located in the center of the room at a height of 1.5 m above the table, which will be considered the task area. Were a different standard chosen, the results would have been different also. However, the general relative performance of the lighting options remain the same.

2.8 The following values for luminous conditions resulting from the use of a 60 W incandescent lamp in such a room will be used as the reference standards for comparison:

- illuminance at the task area (table top): 75 lux
- average horizontal illuminance in the room: 25 lux
- maximum source luminance at a 75° angle: 3000 cd/m^2

2.9 The lamp characteristics that will be used as the reference standards are:

- lamp luminance:	20,000 cd/m^2
- correlated color temperature:	2750 K
- color rendering index:	100
- luminous flux of the lamp:	730 l m
- power consumption:	60 W
- luminous efficacy: (energy efficiency)	12 lm/W
- lamp life:	1000 h

Selection of Lamps for Comparison

2.10 The lamps selected for comparison must ideally be able to produce luminous conditions equivalent to those of the reference standards described earlier and should be commonly used or commercially available on the market in developing countries. In practice however, households which use kerosene wick lamps for lighting have a much lower lighting standard than those which use electricity. Eighteen kerosene lamps or 60 candles have to be used at the same time to obtain a lighting situation comparable to that of the chosen standard, and this is not very appropriate. Therefore, lighting sources taken into account in this report are selected according to their existence and use in developing countries rather than on their comparison with the chosen standard.

2.11 Reliable and accurate data are available for electric lamps based on tests from certified testing laboratories and there is no need to repeat these tests. Most lamp types are available in a range of different light outputs of which only lamps with outputs similar to a standard 60 Watt incandescent lamp are selected. Annex 2 gives a general overview of electric lamps with a much higher luminous output than the 60 Watt incandescent lamp; electric lamps with a very low luminous output are not considered.

2.12 Data for non-electric lamps are not as readily available as those for electric lamps. Therefore, samples of the major types of non-electric lamps were selected for testing in the laboratory 6/ and are listed in Table 1; more details are given in Annex 3. Time and budget constraints limited the number of non-electric lamps that could be tested. Factors such as lifetime of the lamp and spectral power distribution, which have been tested extensively for electric lamps, could not be measured for non-electric lamps and estimates were used instead.

Features Tested

2.13 The lamp tests conducted in the laboratory included measurements of the following lamp characteristics and the luminous conditions of the room. The lamp characteristics included: luminous flux, luminous intensities, chromacity and fuel consumption. Measurements resulting in an acceptably accurate outcome can only be done in a certified laboratory; it is possible to conduct field measurements, but these are both time consuming and less accurate. The luminous conditions in a room have been calculated, based on the characteristics of the lamp, the luminaire and the room.

6/ Institute of Lighting Technology; University of Technology; Berlin, Federal Republic of Germany.

III. THE RESULTS

Overview of Test Results of Non-Electric Lamps

3.1 The performance of non-electric lamps can only be measured with less precision than that of electric lamps (see Annex 3). An overview of the characteristics is given below in Table 1. Three points should be noted here about these characteristics: First, in view of glare limitation, lamps with high luminances should be shielded from the users' eyes to prevent them from stress and fatigue. According to international recommendations for the lowest quality class of glare control, luminances of 15,000 cd/cm^2 should be at an angle of 21 degree or more from the line of sight in case the luminance has a vertical luminous area. This can be easily achieved by locating the lamp sufficiently high above eye level. All types of Welsbach lamps 7/ require (but only a few have) some kind of protective shielding.

3.2 Second, with a view to colour aspects: in the actual tests, due to the afore mentioned constraints, the spectral power distribution could not be measured and the colour rendering index could not be calculated. However, from subjective appraisals by the experimenters the colour rendering was estimated as poor for Welsbach mantle lamps which emit greenish light and the colour appearance perceived was unnatural. The incandescent lamps (candle, wick and carbide lamp), being nearly black body radiators, have excellent colour rendering indices and natural colour appearance.

7/ Pressurized kerosene and petrol mantle lamps.

Table 1: COMPARISON OF NON-ELECTRIC LAMPS WITH STANDARD LAMP

	Flux [lm]	Lmax [cd/cm^2]	CCT [K]	CRI [Ra]	Luminous Efficiency [lm/W]	Equiv. Number of Lamps	Specific Fuel Consumption [kg/klmh]	Life of Lamp [hours]
Candle	12	10,000	1970	excellent	0.2	60	0.5	-
Kerosene wick lamp	40	12,000	2160	excellent	0.1	18	0.8	4500
Carbide lamp	200	100,000	2320	excellent	0.7	3.7	0.25	1500
Butane lamp	400	100,000	3030	poor	1.0	1.8	0.075	7500
Kerosene mantle lamp	400	120,000	2830	poor	0.8	1.8	0.1	7500
Gasoline mantle lamp	500	160,000	2760	poor	1.2	1.5	0.07	7500
60 W reference lamp	730	20,000	2750	excellent	12	1	0.2 a/	1000

a/ given in: kWh/klmh

Notes:
- L_{max}: maximum luminance of the lamp
- CCT: Correlated Colour Temperature
- Energy Efficiency in [Lm/(J/s)] = [lm/W], with combustion heat value of the fuel in Joules [J]; efficiency of electricity production: 30%;
- Equivalent number of lamps is the number of lamps required to produce the same luminous flux as the reference 60W lamp;
- Specific fuel consumption is the fuel required to produce 1 Lumen-hour (Lmh);
- Colour Rendering Index cannot be measured easily for non-electric lamps (even in the Laboratory); a scale is used here: above 80 Ra: excellent; below 80 Ra: poor.

3.3 Third, with a view to the lighting level, the figure of the equivalent number of lamps in Table 1 (third column from right side) shows how many lamps are required to produce the same luminous flux as produced with a 60W reference lamp. The figures in Table 1 are theoretical figures because they consider the light emitted in all spatial directions. Because all the non-electric lamps considered have a light distribution with the highest intensity in a horizontal direction and virtually no intensity vertically downward (thus, the shadow of the lamp socket/support falls on the task area), the luminous flux of these luminaires will be lower than for the reference lamp. A smaller proportion of the lamp flux will leave the luminaires directly, unaffected by reflection or transmission losses in the luminaires. Moreover, the relative luminous intensity distribution will be wider for the non-electric lamps unless special optical systems are used. This result in more uniform illuminances at the horizontal plane but lower illuminances at the table top below the lamp. As a consequence, even more non-electric lamps will be required in practice to obtain the same lighting condition as with the standard lamp than was measured in the laboratory.

Overview of Characteristics of Electric Lamps

3.4 Manufacturers' data are available on all aspects of electric lamps and no additional tests were required. A summary of these data is presented in Table 2 below. In general, the average luminous flux or light output of electric lamps decreases with their lifetime and a conservative estimate of about 10% has been taken, both for incandescent and fluorescent lights. The light output of fluorescent lamps depends on the ambient temperature of the lamps and excessively high temperatures may result in a reduced output. Direct Current (DC) power operation (such as from batteries and/or photovoltaic solar panels) of fluorescent lamps requires special electronic ballasts (e.g. the PL x W DC lamps) or other type converters; lamps with built-in ballasts are not suitable for DC power supply.

Table 2: COMPARISON OF ELECTRIC LAMPS WITH STANDARD LAMP

Lamp Model	Flux [lm]	Lmax [cd/m²]	CCT [K]	CRI [Ra]	Luminous Efficacy [lm/W]	Eq.nr. of Lamps	Lamp Life [h]	Power Input [W]
TL 8W/29	410	10,000	3000	51	27	1.8	5000	15
TL 8W/82	450	10,000	2700	85	30	1.6	5000	15
PL 9W	600	25,000	2700	85	46	1.2	5000	13
PL 9W DC	600	25,000	2700	85	50	1.2	6000	12
PLC 10W	600	25,000	2700	85	39	1.2	5000	15.4
PLC*11E	600	25,000	2700	85	55	1.2	6000	11
SL*13	650	25,000	2700	85	50	1.2	6000	13
GLS 40W	430	12,000	2700	100	11	1.7	1000	40
GLS 60W a/	730	20,000	2750	100	12	1.0	1000	60
GLS 75W	960	26,000	2780	100	13	0.8	1000	75
SL*18	900	25,000	2700	85	50	0.8	6000	18
PL 11W	900	25,000	2700	85	63	0.8	5000	14.2
PL 11W DC	900	25,000	2700	85	64	0.8	6000	14
PLC 13W	900	25,000	2700	85	53	0.8	5000	17.1
PLC*15E	900	25,000	2700	85	60	0.8	6000	15
TL 13W/33	930	10,000	4000	63	50	0.8	5000	18.5
TL 13W/82	1000	11,000	2700	85	54	0.7	5000	18.5
TLD 15W	1000	8,000	2700	85	44	0.7	8000	22.5
TLDHF 16W	1400	11,000	3000	85	74	0.5	8000	19

a/ Standard lamp. 'GLS' lamps are incandescent; all other are fluorescent; brand name all lamps: Philips; See Annex 2 for explanation terminology.

Notes:

1. CCT: Correlated Color Temperature, gives an indication of the color of light produced. Most fluorescent lamps are available in various color temperatures with the exception of fluorescent lamps specially designed for domestic lighting which are made for lower color temperatures. For this survey lamps with a color temperature close to that of the 60W reference lamp were selected. One exception is the TL 13W/33 lamp which has too low a CRI.
2. CRI: Color Rendering Index [Ra], should not be lower than 80 for domestic applications: the TL 8W/29 and the TL 13W/33 are not acceptable in this respect.
3. Fluorescent lamps must be operated with a ballast to control the lamp current. These ballasts cause power losses which are taken into account in the given efficiencies. SL* and PLC*--E lamps have built-in ballasts: for these lamps the consumed power of lamp plus ballast is equal to the lamp-wattage designation.
4. Equivalent number of lamps refers to the number of lamps required to obtain the same illuminances produced by the 60W reference lamp. Because electric lamps can be mounted at inclinations with their maximum luminous intensity vertically downwards, the restriction mentioned earlier for the non-electric lamps is not valid here and the ratio of the luminous fluxes of the lamps to those of the GLS 60W represents simply the equivalent number of lamps.

Comparison of Electric and Non-Electric Lamps

Introduction

3.5 In this initial comparison between electric and non-electric lamps, four factors are discussed: energy efficiency (this includes both fuel consumption and light output); fluctuations in voltage as a major cause for enormous variations in energy efficiency; the resulting luminou conditions in a room; and the need for more field data on lighting issues. A financial comparison based on European cost figures for lamps and energy concludes this chapter. No attempt is made to present an economic analysis of lighting options: only the financial aspects from the user's point of view are shown here. The results can be quite different for different countries, because of subsidies and taxes, and it is beyond the scope of this report to shed light on the situation in general. This report gives the baseline data and provides a framework for further country-or location-specific analysis.

Energy Efficiency/Luminous Efficiency

3.6 There are considerable differences in energy efficiency (in [lm/W]) between different types of lamps. For example, modern electronic fluorescent lamps are four to six times more efficient than ordinary electric incandescent lamps; pressurized kerosene lamps are eight times more efficient than kerosene wick lamps. The differences between lamps in the various categories under ideal conditions are even more pronounced: the most energy efficient kerosene lamp is 4.5 times 8/ less efficient than the least efficient electric lamp, or approximately 20 times less efficient than the most efficient electric lamp. Diagram 1 clearly shows that the efficiencies of the three different types of lamps for domestic use fall in three distinct classes: fluorescent lamps with efficiencies ranging from 30 to 75 lm/W; incandescent lamps with efficiencies of about 12 lm/W and non-electric lamps with efficiencies of about less than 1 lm/W.

Response to Voltage Changes

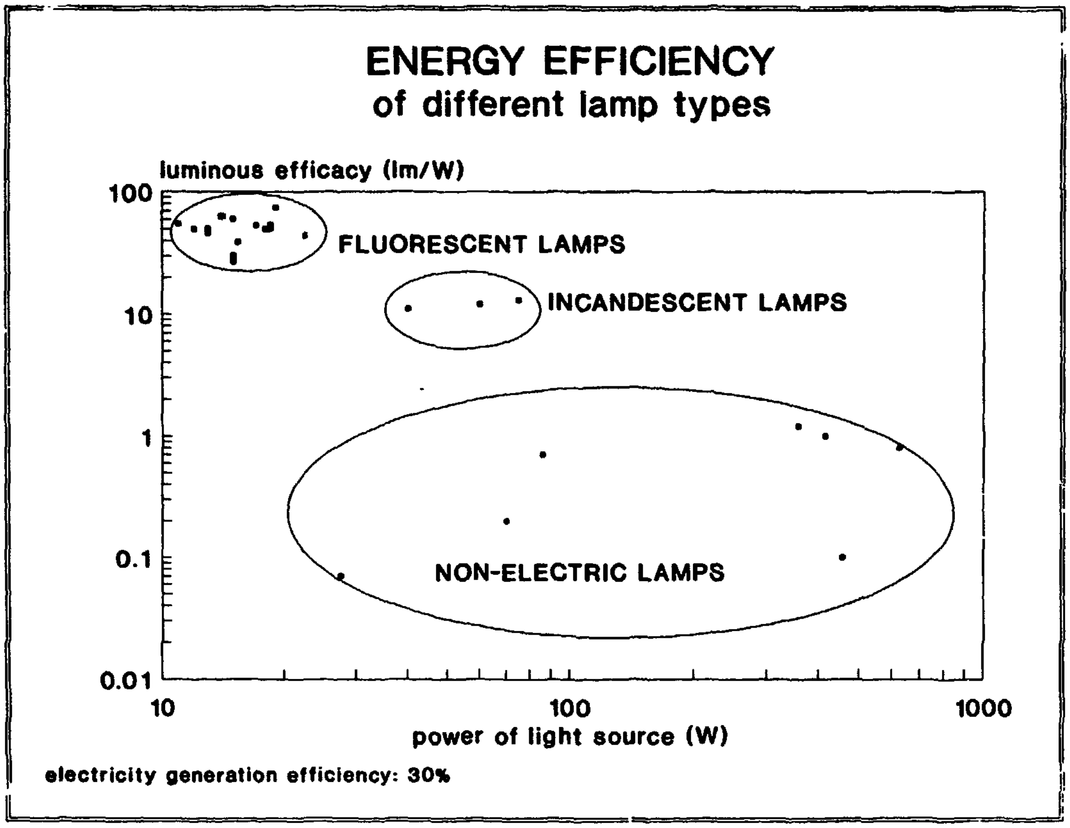
3.7 Under less than ideal conditions, such as a deviation from the rated voltage, modern fluorescent lamps are preferred over incandescent lamps. The emitted light output of an incandescent light drops dramatically when the mains voltage drops by only 10%, whereas a fluorescent lamp continues to give a normal output. A fluctuation of about 7% is considered acceptable in certain industrialized countries such as the United States, but in many developing countries variations are often greater than this, particularly so during the evening peak hours of 7 to 10 pm. Diagram 2 shows the relative gains and losses in efficiency associated with voltage changes. The efficiencies of incandescent lamps decrease considerably at lower voltages, whereas those

---

8/ This includes a thermal generation efficiency of 30% for electricity. Often one compares the energy efficiencies at end-use of kerosene and electricity, which means that the range given above is 3.3 times higher, or electric lamps are 15 to 65 times more efficient than the most efficient kerosene lamp if electricity is from a primary source, (i.e. not from a hydro electric source).

of fluorescent lamps tend to increase slightly. If the voltage drops by 20%, the luminance of an incandescent lamp drops to less than half of the rated output. However, the lifetime of incandescent lamps changes dramatically with the rated output as shown in diagram 3. For example, if the voltage is 110% of the rated value, the lifetime of incandescent lamps is decreased by 80%. 9/

Diagram 1



9/ The life time of a 60 W reference lamp operated at 242 volt (normally: 220 volt) is reduced to 200 hours (normally: 1000 hours).

Diagram 2

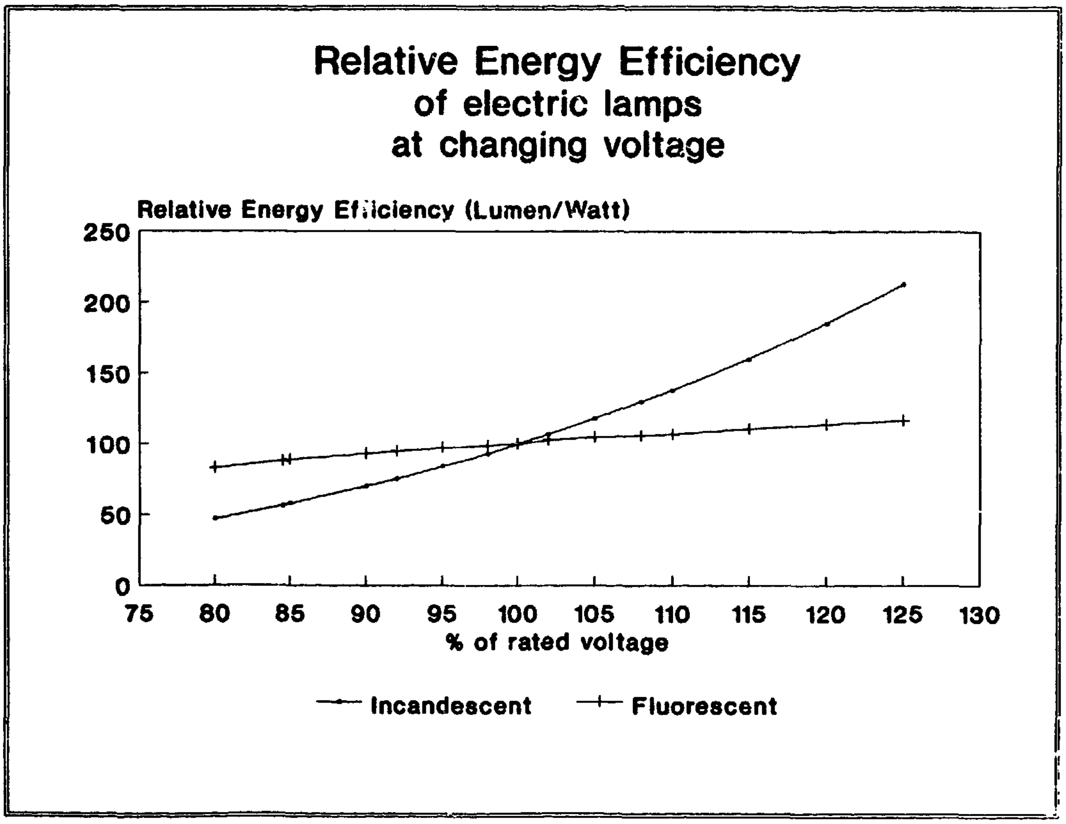
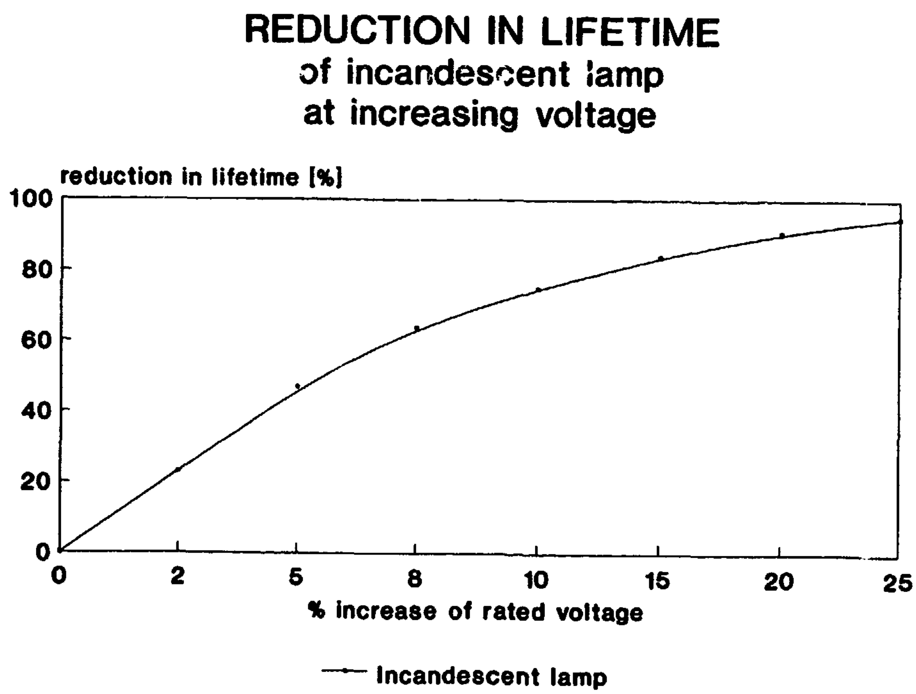


Diagram 3



Luminous Conditions

3.8 The resulting luminous conditions in a room are as important as the energy efficiency and fuel consumption. Factors such as reflectivity of the walls and ceiling, and reflectors attached to the luminaire determine the distribution of light intensity in the room, and therefore the acceptability of the light quality to the user. A room with mud walls and a reference lamp will give a lower illuminance at the task area than the same lamp in the same room with whitewashed walls. Kerosene lamps, for example, emit most of their light in horizontal directions and almost nothing in vertical directions, whereas electric lamps can be mounted in such positions as to emit their maximum intensity in arbitrarily chosen preferred directions. Furthermore, behavioral patterns such as adjusting the lamp setting, cleaning glass covers, replacing mantles, and polishing reflectors will cause variations in the performance of lamps and resulting illumination. Therefore, additional information is needed to identify the preferences and practices of users under actual conditions.

Need for Field Data Collection

3.9 The Indonesian and Indian fuel consumption data described in the introduction may be used here to explain some of the difficulties related to lighting. It is likely that as people change from non-electric to electric light, they will tend to use more light. In parts of India where a hurricane kerosene lamp is used, residents of a non-electrified village receive 4.5 - 9 times less artificial light than residents in electrified villages. In Indonesia where many Welshbach kerosene lamps are used, residents of non-electrified villages receive an average of 3.3 times more artificial light than residents in electrified villages. This appears anomolous: either people are content with less light, or the consumption estimates overlook some other uses of kerosene such as for cooking, 10/ or other factors not described in the study play a role here. In order to make more reliable estimates of the load forecast for rural electrification and to make recommendations for conservation measures, tests are needed to yield accurate data on the performance of lamps. Such tests include field data collection and should focus on actual performance of lamps and preferences of users. Fuel consumption should be measured or surveyed and spot checks of the range of illumination should be made. Data collection should further concentrate on the user's perception of lighting: why is kerosene still used while electricity is available in the village; why are certain types of kerosene lamps preferred; role of income on choice of lighting source; availability of fuel; etc.

Discussion of Results

3.10 This report shows that electric lamps are better than non-electric lamps in four ways: (a) they are more energy efficient; (b) they are more cost-effective; (c) they have better technical performance; (d) they have superior practical features. For example,

---

10/ The survey indicated that 80% of the kerosene population uses a pressurized kerosene lamp (Welshbach lamp).

Table 3 shows that the standard electric incandescent lamp is at least three times more energy efficient than most non-electric lamps. This relationship holds under laboratory conditions and does not take into account the spatial intensity distribution of the light. If the latter is taken into account, non-electric lamps will be even more inefficient than is shown in Table 3.

3.11 From the financial point of view, electric lamps are preferable, as demonstrated in the least-cost analysis for equal lighting levels presented below (see annexes 2 and 3 for financial data). Although different countries have different scenarios to distribute costs for use of electricty and kerosene among the users, it is highly unlikely that a scenario can be found where kerosene lighting is cheaper than electric lighting (from the financial point of view, in case equal lighting levels are considered) simply because electric lamps are much more energy efficient than non-electric lamps. The analysis takes into account all costs except wiring costs and connection charges. In-house wiring costs are not considered on two grounds: they are highly case-specific, and electricity will be used for other purposes than lighting only. Connection charges are not considered because of the same reasons: taxation and subsidies are different in every country making it very case specific; moreover, the analysis will propose on the basis of all other costs, an amount of money that reasonably can be paid as connection charge.

3.12 Under the chosen financial scenario, the electric standard lamp is at least five times cheaper than the financially most attractive non-electric lamp. 11/ Unlike non-electric lamps, electric lamps have a convenient spatial light distribution in that the light output can easily be directed towards the work area. The use of reflectors can even magnify this effect. In addition, the color rendering of electric lamps is quite superior to that of the most efficient non-electric lamps. Electric lights do not require regulation of the output or much attention with respect to maintenance. Non-electric lamps, on the other hand, need considerable attention and maintenance.

Table 3: LEAST-COST ANALYSIS - NON-ELECTRIC LAMPS a/

Type of Lamp	Cost per 1000 kLmh (US$)	Number of Times as Expensive than Reference	Number of Times Less Energy Efficient than Reference
Non-electric:			
Candle	1071	117	18
Kerosene Wick	349	37	36
Carbide	2396	257	5.1
Butane	70	7.5	3.6
Kerosene Mantle	53	5.6	4.5
Gasoline Mantle	73	7.8	3.0
Electric: (Reference)			
Standard 60W incandescent lamp	9.73 b/	-	-

a/ Electricity: $0.10/kWh; kerosene: $0.30/liter; gasoline: $0.60/liter the analysis assumes equal lighting levels for all lamps. Carbide is not used any more as a commercial fuel, therefore, its costs were prohibitively high.

b/ Efficiency of electricity generation: 30%. Equipment costs are amortized at a discount rate of 10%.

11/ This does not take into account connection charges and wiring cost.

3.13 The energy efficiency of the kerosene mantle lamp is about eight times higher than that of the kerosene wick lamp; its fuel consumption and light output are respectively eight and thirty-three times higher than that of the wick lamp. People who change from a wick lamp to a mantle lamp will not experience savings in fuel; on the contrary, they will see a rise in kerosene consumption as well as in light output thereby significantly improving their lighting conditions.

3.14 Fluorescent lamps are more attractive than incandescent lamps: they are at least 3.9 times as efficient as incandescent lamps; they are at least 1.3 times more cost effective in the presented scenario. It must be noted, however, that the financially most attractive fluorescent lamp, the TL 13W/33, is not a good option because of its color rendering index. It is presented here to show that cheap fluorescent lamps exist with a purchase price comparable to that of two kerosene wick lamps and a light yield more than 10 times that of the combined light yield of two kerosene wick lamps.

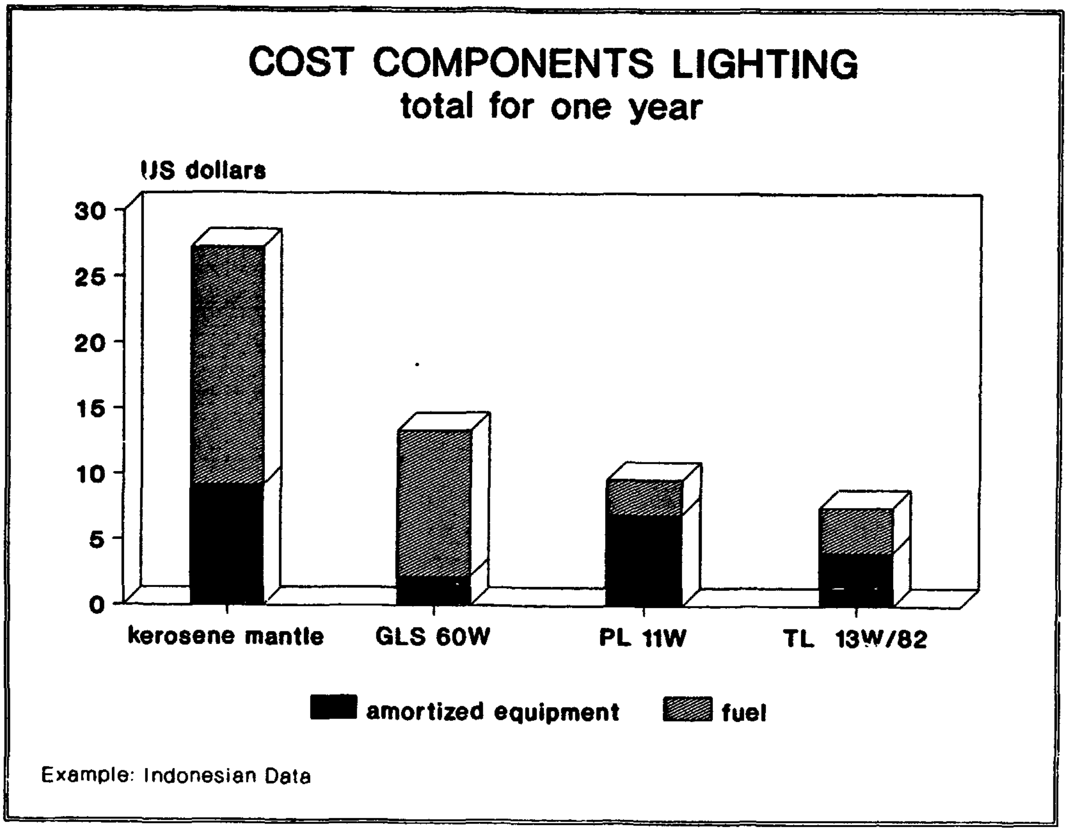
Table 4: LEAST-COST ANALYSIS ELECTRIC LAMPS

Type of lamp	Cost per 1000 klmh [US$]	Number of times less expensive than Reference	Number of times as efficient than Reference
fluorescent lamps			
PL 9W	7.63	1.3	3.9
PL 11W	5.67	1.7	5.3
TL 13W/33	3.94	2.5	4.2
TL 13W/82	4.11	2.4	4.5
standard 60W (reference)			
incandescent lamp	9.73	-	-

Equipment costs (lamp, ballast) are amortized;
discount rate = 10%; electricity: $0.10/kWh
the analysis assumes equal lighting levels for all lamps

3.15 Diagram 4 shows an overview of annual costs for lighting for four different types of lamps under indonesian conditions (see next chapter). The cost are divided into two broad categories: fuel costs and equipment costs. Fuel costs contribute as much as 80% to the total cost of lighting in case of incandescent lamps; for the most cost effective fluorescent lamp this is reduced to approximately 50%. Furthermore it is shown that equipment costs for pressurized kerosene lamps are of the same order of magnitude as the total costs of lighting for the most effective lamp.

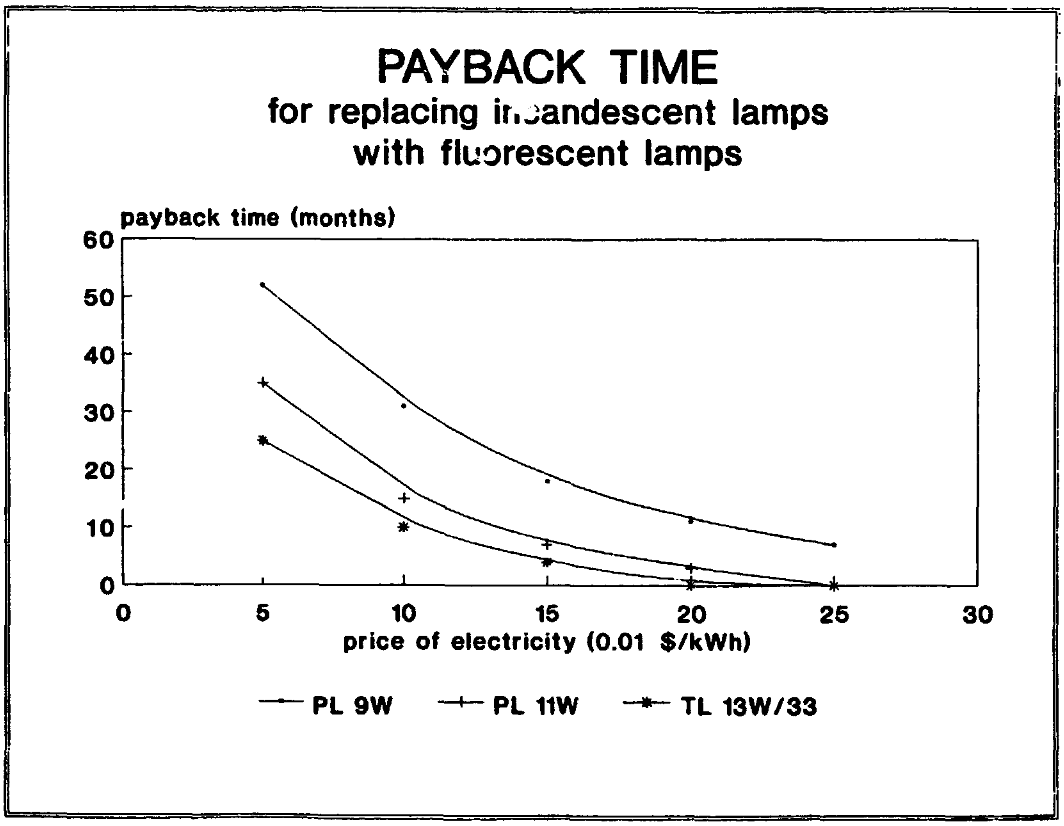
Diagram 4



3.16 The financial internal rate of return for a change from the standard (incandescent) lamp to one of the fluorescent lamps presented in Table 4 ranges from 24% to 106%, depending on the prevailing electricity tariffs. From the energy conservation standpoint this change is highly recommended since it could save up to 80% of the energy used per lamp.

3.17 Diagram 5 shows the sensitivity of payback times to electricity prices in changing from incandescent lighting to the three types of fluorescent lighting presented in Table 4. Assuming electricity tariffs of $0.10/kWh and 1,100 operating hours per year, payback times range from 10 months to 2.5 years depending on the specific fluorescent lighting source. For an electricity tariff of $0.15/kWh, these figures range from 4 months to 1.5 years.

Diagram 5



Conclusions

3.18 If users switch from non-electric to electric lamps, they will experience a substantial improvement in lighting conditions. Because of the large energy efficiency differences between electric lamps and non-electric lamps, it is quite likely that they will also save energy on lighting (initially, when only a few lamps are used). Whether or not they also save in financial terms depends on the particular situation (prices of fuel, electricity and equipment; costs of wiring; connection charge; usage of lamps; etc.).

3.19 It is difficult to compare lighting situations obtained with non-electric and electric lamps. Electric lamps have a low power (the lamps tested ranged from 10 W to 30 W for fluorescent lamps, 40 W to 60 W for incandescent lamps) while non-electric lamps normally have much higher power (70 W to 700 W for the tested lamps). Energy efficiencies are quite different also: for fluorescent lamps it ranges from 25 lm/W to 75 lm/W; for incandescent lamps it is about 12 lm/W; and for non-electric lamps it is typically lower or equal than 1 lm/W.

3.20 Fluorescent electric lamps for domestic use are 2 to 7 times more energy efficient than incandescent electric lamps. Payback times depend largely on electricity prices, type of equipment, user patterns and equipment costs, and generally ranges from a few months to a few years.

3.21 It is recommended that some field tests be conducted as part of ongoing projects; preferably (rural) electrification projects or household energy strategy projects. Data on user related aspects of lighting should be collected, like usage; number and types of lamps; regulated light output; cost aspects; etc. The outcome would be to have a better understanding of the lighting situation and to design a method to estimate initial load patterns of electrification schemes.

IV. EXAMPLES

Introduction

4.1 Comparisons of electric lighting and kerosene lighting are made difficult, if not meaningless, by the cact that these lighting sources have many different characteristics. In practice, however, while estimating a load factor for a proposed rural electrification project, this comparison often has to be made. For illustrative purposes, the next chapter gives an overview of a typical lighting situation found in practice, based on the micro survey mentioned earlier. It furthermore discusses the lighting situation in Indonesia using actual financial data. 12/

In Practice

4.2 In practice people use different lighting levels which makes a comparison between different lighting options quite difficult. Each option involves different costs, different light outputs, and different energy consumption as is shown in the following example. Four different categories of lighting are suggested from observations in practice: (a) kerosene wick lamps: one or two lamps are found in the house operating at very low luminance, just to prevent people from bumping into furniture;

12/ Indonesia: Rural Electrification Overview, Nov. '86; World Bank Report No 6144-IND

(b) kerosene mantle lamps: one or two, operating at normal luminance during the evening hours; (c) electric light from grid power: the average in the survey was 4 incandescent lamps (of 40W and 60W) and two fluorescent lamps (40W), some of which operated throughout the night for security reasons; and (d) electric light from a (car) battery: one or two fluorescent 12 Volt DC lamps are used during the evening hours.

4.3 Costs, light output, energy consumption, and the cost/light output ratio for these four different lighting options are presented in diagram 6 below. Basic cost figures for equipment, tariffs, connection charges, fuel costs etc. are given in Annex 4.

4.4 Diagram 6 clearly shows that kerosene wick lamps provide the cheapest lighting alternative, however, obtained lighting levels are extremely low. The next cheapest alternative comprises of two options which are approximately on the same lighting level: kerosene mantle lamps and fluorescent lamps connected to a (car) battery. Light output and costs for the mantle lamp are slightly lower than for the battery/lamp combination, but energy consumption is much higher. The next and most expensive option is electric lighting using the electricity grid: the costs are roughly twice that of the previous option but the total light output is more than four times higher.

4.5 A comparison of the cost effectiveness of the options described above (in terms of klmh output per dollar input) shows 3.1; 12.6; 15.0; and 77.7 klmh/$ respectively for the kerosene wick lamps; kerosene mantle lamp; electric battery/lamp; and electricity grid/lamps. Such a comparison is not directly applicable since the light output of the different options is not comparable (not even approximately). However, it does show that the kerosene wick lamp is the cheapest option available.

Rural Electrification

Introduction

4.6 This example concentrates on the following questions: what if kerosene lighting is to be replaced by electricity? Can savings obtained from electric lighting pay for the transition from kerosene lighting to electric lighting; and how can introductory charges/costs for electricity supply be made more attractive to the user? Unlike the previous example, approximately equal lighting levels are considered: two kerosene mantle lamps, one standard reference lamp (gives 9% less light than the kerosene option) or one 11 W (14.2 W_e) fluorescent lamp (gives 16% more light than the kerosene option).

Breakeven Electricity Supply Costs

4.7 As shown in the previous chapter, electric lighting is far more attractive to the user (if and when electicity is available) than non-electric alternatives. In many developing countries, however, the issue of conversion to electric lamps involves the degree to which investments in distribution and connection are justified. Utility companies generally recover the cost of connecting a customer to the electricity grid from users through a one time connection charge, and finance power generation costs by charging a kWh price. As illustration, figures for these costs in Indonesia are given in Table 5. The analysis compares the annual cost of lighting for electric lamps and kerosene lamps in case the light output is approximately similar. In-house wiring costs are not considered on two grounds: they are highly case-specific, and electricity will gradually be used for other purposes than lighting only.

Table 5: INDONESIA: OVERVIEW LIGHTING OPTIONS

	Kerosene Press. Lamp	GLS 60W	PL 11W a/
Lamp			
equipment cost (US$)	25	0.93	11.76
lifetime (hr)	7300	1000	5000
" (yr)	3.3	0.5	2.3
Ballast			
equipment cost	-	-	6.23
lifetime (hr)			25000
" (yr)			11
Fuel			
fuel cost per unit	0.17 $/liter	0.09 $/kWh	0.09 $/kWh
consumption of fuel/month	18.3 liter	11.0 kWh_e	2.6 kWh_e
" " (kWh equivalent) (primary units)	640 kWh	37 kWh	8.7 kWh
Lighting			
hours of lighting per day	6	6	6
luminous flux of lamp (lm)	400	730	930
nr. of lamps required to obtain same light level	2	1	1
total system light output (lm)	800	730	930
luminance relative to kerosene lamp	-	-9%	16%
Cost overview			
annualized equipment costs	18.4	2.2	7.0
fuel cost	36.2	11.2	2.6
total costs for 1 year	54.6	13.4	9.6
" (per month)	4.5	1.1	0.8

a/ Electric load of lamp and ballast is 14.2 Watt.

Note

Prices/costs in US$ ('87); equipment costs: prices in Dfl converted at Dfl 2.1 = US$1; fuel costs, and connection charges: Indonesian data, Rp1000 = US$ 1

4.8 The analysis shows that lighting alone cannot fully pay for these connection charges. At current electricity and kerosene prices, savings amount to approximately $40 per year, while actual connection charges range from $65 to $100. It must be noted that, when people change from kerosene lamps to electric lamps, there are other benefits beyond financial savings which cannot easily be quantified: better quality lighting; more light; higher convenience; no noise, smoke, fire danger, etc.

4.9 A major reason for not being able to afford the use of electricity, even if electricity is available at the village level, is the up-front connection charge. In-house wiring can physically be done over a certain period of time gradually distributing the actual costs, but the connection charge in Indonesia normally has to be paid in full before the connection is made. To alleviate a poor family's financing problems, the costs could be spread out in the form of a higher kWh unit price, as actually is done in some countries. This allows the utility company to fully recover the connection charges in a certain period of time. The analysis shows that the maximum kWh price to equal costs for lighting with kerosene under approximately similar lighting conditions is on the order of $0.40 to $1.75 per kWh depending on the load factor, or the type of electric lamps used. In practice however, this price will vary according to the circumstances.

4.10 Table 6 shows that a customer who uses electric lighting on a level he was used to with kerosene lamps, will save more than $40 per year when he switches to electricity. In theory, he would be able to pay a connection charge of about this amount and not feel the difference on his budget. The user's problem at the moment is that he has to finance this connection charge before he is able to experience the potential savings. The user would much prefer that the connection charge is spread out over a longer period of time.

Table 6: INDONESIA: SAVINGS AND PAYBACK

TIMES LIGHTING OPTIONS

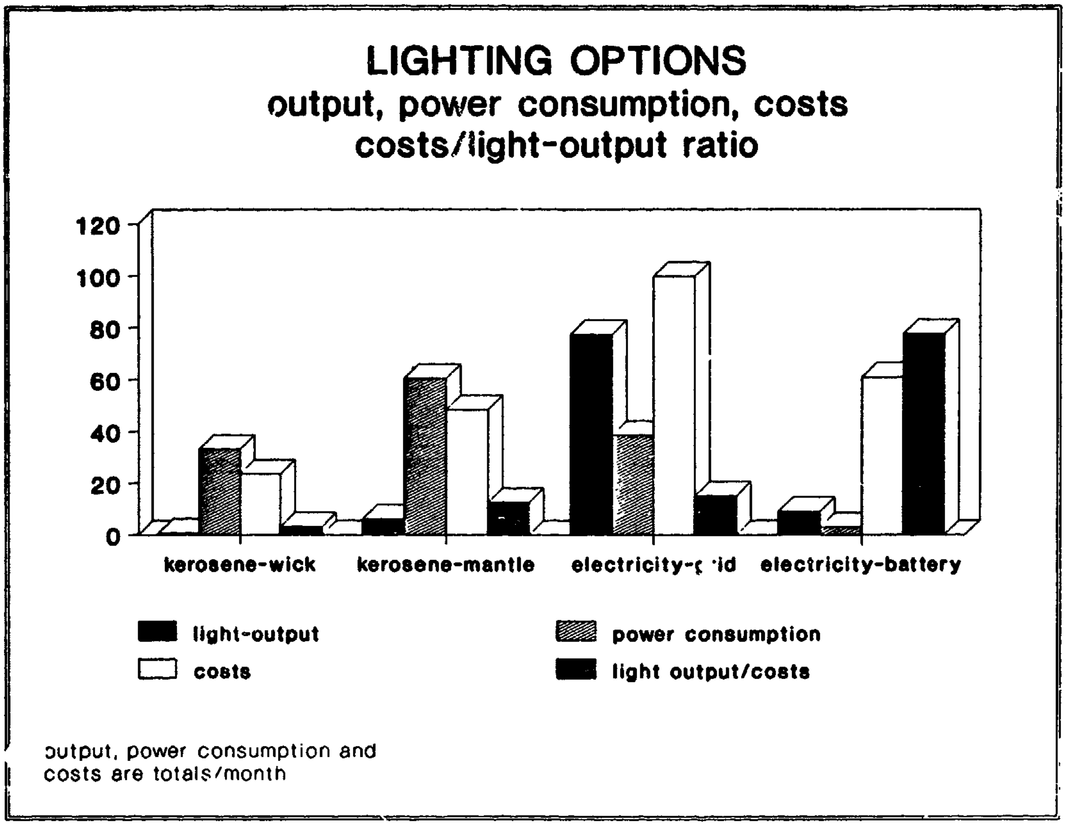
		GLS 60W	PL 11W
Savings in first year (relative to kerosene)	[$]	41.2	45.0
Payback time for connection charge of $100	[years]	2.4	2.2
Higher kWh price to equal costs of kerosene lighting	[$/kWh]	0.41	1.75

4.11 For such a situation where e.g. the electricity company replaces the connection charge by a higher kWh price for electricity consumed, Table 6 shows the highest price of electrity that could be charged. The user pays for lighting an equal amount of money per year as he was used to with kerosene. At the same time, he pays a higher price of electricity for a fixed period of time, e.g. two and a half years, after which he starts paying the normal price of electricity and starts experiencing savings. The benefits to the user are clear: no up-front money for connection costs gives him the opportunity to start using electricity as early as possible. The major advantage for the electricity company is that people will switch earlier to electricity which increases the load factor. In reality, users will soon start using incremental lamps and other appliances, such as radio, iron, and rice cooker and hence, will end up paying a higher electricity bill thereby experiencing a higher standard of living. If this happens, a higher load factor will be the result and the connection charges will be paid much faster than within the planned period of time. If incandescent lamps are used, a charge of $0.41 per kWh could be asked; if fluorescent lamps are used, $1.75 per kWh is affordable; in both cases the user pays not more for lighting than he was used to with his kerosene lamps and he receives approximately equal lighting levels.

Conclusions

4.12 Lighting options are difficult to compare because major quality differences exist between them (see diagram 6). However, for the case of Indonesia, a number of options exist with approximately equal lighting levels and the comparison is relatively easy. The differences are stunning: the kerosene option consumes 17 to 73 times more energy than the electicity options. The user pays 4 to 5.7 times more money for the kerosene option although it gives him an inferior quality of light. However, the cash requirements for kerosene lighting come in a timely fashion and the user does not perceive much of a burden. Although kerosene lighting is more expensive than electric lighting, the user finds it difficult to change to electricity simply because he needs to finance a rather large sum of money (connection charges, wiring costs, equipment costs) before he is allowed and able to use electricity. Lighting alone cannot pay for these connection costs within one year. After connection to the electricity grid, people will soon start using other appliances than luminaires and it is not appropriate to use solely savings from kerosene lighting as a means to write off connection charges.

Diagram 6



4.13 Economic analyses of the lighting situation are not easy to make and quite a few steps have to be taken before a proper evaluation can be made: kerosene consumption for lighting can be estimated through surveys; lighting levels can be estimated through field measurements or through baseline figures given in this report; quality of lighting can be estimated through surveys using the guidelines of this report. Electricity demand can be projected over a certain time using results from monitoring of other electrification programs in combination with surveys on projected electricty use; quality of life improvements should be valuated in terms of lighting and other uses of electricity. Finally, four different balances (energy consumption, lighting conditions, quality of life, financial requirements) should be evaluated to finalize the economic analysis.

ANNEX 1

Glossary and Introduction to Photometrics

This section gives a description of photometric quantities and related terms which are used in the main text of this report. It is meant to familiarize the reader with the concepts without the intention of being precise. Exact definitions are given in the International Lighting Vocabulary.

Light Sources

1. The terms "lamp" and "light source" are used loosely in colloquial language. However, strictly speaking the term light source refers to any surface or object that emits light. In this sense an illuminated surface that reflects or transmits (part of the incident) light is a light source.

Lamp is the term used for a light source that uses another form of energy to produce the light that it is emitting.

Luminaire is the term used for a device containing one or more lamps, parts for fixing and protecting the lamp(s), and elements for controlling the light from the lamp(s) in the desired directions.

Light source in this report is used as a general term that may apply to a lamp, to a luminaire or to both.

Note: For other reflecting or transmitting surfaces existing in the room, the term (secondary) light sources is used.

General Photometric Quantities

Luminous flux is the quantity used to express light power;
Symbol: Φ unit: lumen, lm

Quantity of light (during a period of time) is the sum total of luminous flux (emitted or received) during that period;
Symbol: Q; unit: lumen-hour, lm.h

Illuminance (at a point in a plane) is the quantity used to express the level of illumination at that point in the plane;
Symbol: E; unit: lux, lx

Note: The horizontal illuminance E_{hor} at a point P is the measure for the illumination of a horizontal surface put in P, whereas the vertical illuminance E_{vert} gives the illumination of a vertical surface in P.

Luminous intensity (of a (secondary) light source in a given direction) is the quantity used to express how much light from the source is concentrated in that direction;
Symbol: I; unit: candela, cd

Luminance (of a (secondary) light source in a given direction) is the quantity used to express the brightness of the source;
Symbol: L; unit: candela per square metre, cd/m^2

Lamps

Power consumption (of a lamp) is the power ;used to produce the light output specified. This power is consumed in the form of a fuel, like kerosene, or gas, or in the form of electricity;
Symbol: none; unit: Watt, W

Note: For non-electric lamps the power is calculated from its fuel consumption per unit of time and the combustion heat value of the fuel concerned. Therefore, a comparison of energy consumption in terms of primary energy should take into account the efficiency of generating electricity.

Luminous efficacy (of a lamp), or energy efficiency, is the term that expresses the efficiency of the lamp in transforming another form of energy into visible light;
Unit: lumen per Watt, lm/W

Luminous efficiency (of a lamp) is the ratio of visible light to the total radiant flux emitted by that lamp;
Unit: 1

Electro magnetic radiation of wavelengths roughly between λ 380 and 760 nm incident at the human eye causes visual sensations. The sensitivity of the eye is maximum for radiation of the wavelength $\lambda_m = 555$ nm, that means that less radiant power for monochromatic radiation of this wavelength is required to produce an equally intense visual sensation than for monochromatic radiation of any other wavelength, in other words: the spectral luminous efficiencies $V(\lambda)$ of monochromatic radiation of these other wavelengths to produce visual sensations are lower and per definition $V(\lambda_m) = 1$ for monochromatic radiation of λ_m = 555 nm.

For e.m. radiation of a special distribution $\phi_{e,\lambda}(\lambda)$ of radiant flux its luminous efficiency V is given by the following expression:

$$V = \frac{\int_0^\infty \Phi_{e,\lambda}(\lambda) \cdot v(\lambda) \cdot d\lambda}{\int_0^\infty \Phi_{e,\lambda}(\lambda) \cdot d\lambda}$$

Because the luminous (or visual) effect of visible radiation depends on the spectral distribution of that radiation, luminous quantities can only be introduced by applying the luminous efficiency on the (energetic) radiation quantities if they are to express visual effects. To distinguish between the luminous (or visual) and the radiant (or energetic) quantities, the subscripts v and e are used for the first and the latter resp. For instance: the symbol for the luminous flux is Φ_v (unit: lumen, [lm]) and the symbol for the radiant flux is Φ_e (unit: Watt, [w]):

$$\Phi_v = K_m \cdot V \cdot \Phi_e$$

in which V is the luminous efficiency of the radiation concerned,

K_m is a coefficient of the dimension $[\mathrm{lm.w}^{-1}]$

The quotient of the luminous flux by the corresponding radiant flux is termed the luminous efficacy K of the radiation concerned (unit: $[\mathrm{lm.w}^{-1}]$):

$$K = K_m \cdot V$$

For monochromatic radiation of wavelength λ_m = 555 nm V = 1, so that the luminous efficacy of this radiation equals K_m $\mathrm{lm.w}^{-1}$, which is the maximum possible luminous efficacy: $K_m = 683\ \mathrm{lm.W}^{-1}$

The <u>radiant efficiency</u> η_e of a lamp is the ratio of the radiant flux of the emitted radiation to the power consumed by the lamp (unit: 1)

The <u>luminous efficacy</u> η_v of a lamp is the quotient of the luminous flux emitted by the lamp and the power consumed by the lamp (unit: $[\mathrm{lm.W}^{-1}]$):

$$\eta_v = K \cdot \eta_e$$

note: the above is meant as a more or less simple introduction in photometric terminology; for a more exact terminology the International Lighting Vocabulary (publication CIE No. 17.4, 1987) should be consulted.

<u>Lamp Life</u> (of a type of lamp) is the average time that lamps of this type operate before they fail to perform satisfactorily; Symbol: none; unit: hour, h

<u>Lamp lumen</u> loss factor (of a type of lamp) is the factor that accounts for the decrease over time of the luminous flux emitted by the lamp type, due to lamp aging;

Luminaires

Light output ratio (of a luminaire) is the ratic of the luminous flux emitted by the lamp to the luminous flux leaving the luminaire;

Luminaire loss factor (of a luminaire) is the factor that accounts for the decrease over time of the flux leaving the luminaire, due to the accumulation of dirt on the surfaces of the lamp and luminaire;

Color of the Light and Color Rendering

Chromaticity (of light) is the term used in colorimetry for the color of the light and is designated by its coordinates in the CIE chromaticity diagram;

Correlated color temperature (of light) is the temperature of a radiator of perfect emissivity that is emitting light of the same chromaticity as the light considered;
Symbol: CCT; unit: Kelvin, K

Note: The color of the light emitted by the a so-called "blackbody radiator" is perceived as natural light; when the temperature of the blackbody is gradually increased from low to high, the color changes from red, through yellow and white, to blue. CCT therefore can be used to describe the colour of the light for "near-white" sources. If the chromaticity of light differs too much from that of a blackbody the color is perceived as unnatural.

Color rendering index (of the light of a lamp) is a measure of the extent to which the colors of surfaces and objects illuminated by the light of the lamp are undistorted and perceived as natural
Symbol: Ra, unit: dimensionless

Test Methodology

Luminance

4. Luminance is measured by the number of candelas per square meter (cd/m^2). Instruments for measuring luminance are referred to as luminance meters. Like luxmeters, they consist of a photometer head, a transducer, a display unit, and a power supply. The photometer head of a luminance meter has an optical system in front of the detector. For field measurements reliable and accurate portable luminance meters are

available with an automatic range adjusting capability and a digital display projected in the visual field of the view finder. The range of luminances that can be covered with a measurement field angle of 1° is from 0.1 to 100,000 cd/m^2.

5. Another way to determine luminances, especially the average luminance of a luminaire in a given direction is to calculate it as the quotient of the luminous intensity in that direction and the projected area in the same direction of the luminous parts of the source. This method also is used for determining source luminances for publication in photometric data sheets. The method also could be used for field tests although these only allow an estimate of the luminous intensity to be made.

Correlated Color Temperature, Color Rendering Index

6. The correlated color temperature (CCT) and its chromacity coordinates (x,y) of a lamp can be measured by means of colorimeters. For field measurements reliable and accurate chromaticity meters are available in pocket size that display the chromaticity coordinates and the CCT for white sources simply by pressing the appropriate button. The use of this instrument for field tests in dwellings may be questionable, however, because the tests results describe only one and not the most important aspect of visual discomfort due to the spectral power distribution of the light. Furthermore, for each lamp type these characteristics may be measured only once in the laboratory since they are not expected to change drastically over the course of time. The color rendering index of a source cannot be determined from field tests because this requires measuring the spectral power distribution which can only be done by means of a spectro-photometer in a laboratory.

Luminous Efficacy (Energy Efficiency)

7. The luminous flux [lm] can be measured by placing the lamp in an Ulbricht sphere. This sphere is a perfectly formed ball, sometimes three meters in diameter, with a very smooth and regular inner surface with a known reflectivity. A measure of all light emitted by a lamp can be obtained when this lamp is placed for some time in the center of the sphere. This procedure should be repeated several times to obtain a statistically sound figure. However, non-electric lamps should be kept in the sphere only long enough for them to stabilize enough to produce a reliable luminous flux value because these lamps cause a deposit of soot at the reflective surface of the sphere. In actual tests the optical properties, the sphere factor, of the sphere were calibrated before and after measuring one of the non-electric lamps, and the difference turned out to be less than one percent. In other words, the aforementioned method proved to be viable and did no harm to the sphere. These measurements cannot be made under field conditions; the sphere is not only too large and too vulnerable to use in the field, it needs to be operated under constant temperature.

8. The determination of fuel consumption differs for electric and non-electric lights. In the case of electric lights, fuel consumption can be determined directly by measuring the electric power consumed by the lamp with a dynamo-meter. For non-electric lamps, the fuel consumption is used to calculate power consumption. Fuel consumption is determined by measuring the reduction in weight of the lamp over a specific period of time. The weight is measured by means of an electronic balance that has an accuracy of 0.1 grams. In actual tests, an electric stopwatch was used to read the time at which luminous flux readings were made and the lamp weighed. The power used for light production can be calculated from the measured fuel consumption when the calorific value of the fuel is known and the quotient of the luminous flux and the power used to produce this flux gives the luminous efficacy.

Illuminance luminous intensity

9. The illuminance [lux] of a surface or work area is measured with a lux meter, which is a simple, portable device consisting of a photometer head, transducer, display, and power supply. Measurements under field conditions can be conducted relatively easily. The luminous intensities [cd] in horzitontal directions can be determined from measured vertical illuminances at specified distances from the lamps. The readings should in a photometric laboratory room with darkroom-surfaces through the use of a goniophotometer. The goniophotometer measures the luminous flux emitted by the lamp in a restricted solid angle per unit of solid angle. These measurements cannot be done under field conditions because a darkroom is required. However, a reasonable estimate of the luminous intensity can be made with a number of measurements under field conditions.

ANNEX 2

Principles of Electric Light Production

1. There are three categories of electric lamps for producing light:

(a) incandescent lamps, where the light is produced by the incandescence of a filament heated to a high temperature by an electric current;

(b) discharge lamps, where the light is produced by the electroluminescence of the discharge of a high voltage through a gas; and

(c) fluorescent lamps, where the light is produced by the photoluminescence of phosphors that transform the ultraviolet radiation (produced by electroluminescence) into visible radiation.

2. The term fluorescent lamps is used exclusively for low pressure mercury vapor lamps. High pressure mercury vapor lamps with phosphor coatings are referred to as discharge lamps.

Incandescent Lamps

3. The luminous efficacy of an incandescent lamp depends on the temperature of the filament. Filaments are made of tungsten because of its high melting point and low evaporation rate. Tungsten-halogen lamps permit even higher temperatures because the halogen reduces the migration of the tungsten. However, these lamps require quartz envelopes because of the chemical reaction of halogens with ordinary glass. For different applications different types have been developed, trading luminous efficacy for lamp life.

4. For domestic application, the general service lamps are most widely used. These have a lamplife of 1,000 hours and luminous efficacies ranging from 8 lm/W for a 15 Watt lamp, to 15 lm/W for a 150 matt lamp.

For this study the following lamps are considered:

- 15 Watt	120 lm	8 lm/W
- 25 Watt	230 lm	9.2 lm/W
- 40 Watt	430 lm	10.8 lm/W
- 60 Watt	730 lm	12.2 lm/W
- 75 Watt	960 lm	12.8 lm/W

5. Besides general service lamps, there is a great variety of lamps with internal reflectors which are used in home lighting when more directional lighting is desired:

(a) lamps with internal diffuse reflectors, which have an enforced intensity in the direction of the lamp axis and, when suspended above a table, give a 30% higher illuminance at the table;

(b) blown bulb reflector lamps, which have an internal specular reflector that concentrates the greater part of the light in a cone around the lamp axis, yielding luminous intensities in the cone axis 12 to 15 times higher than those of normal general service lamps; and

(c) bowl reflector lamps, in which an internal reflector shields the filament from view; these are used for indirect lighting or in spotlight luminaires.

Discharge Lamps

6. The luminous efficacies of discharge lamps are greater than those of incandescent lamps: the highest known efficiency is 200 lm/W, produced by a large, low-pressure sodium lamp. The discharge lamps must be operated with a device (ballast) to control the lamp's electric current and some types also require an ignitor. The ballast also consumes energy and should be taken into account when comparing the luminous efficacies of different types of lamps. The term used to designate is "system efficacy". System efficacies may be as much as 30% lower than the corresponding lamp efficacies.

7. The color of the light depends on the pressure end composition of the vapors used in the lamp. Low pressure discharge lamps mainly emit spectral lines characteristic of the vapors. High pressure lamps mainly emit spectral bands, and super high pressure lamps emit a continuum with superimposed spectral bands. As a result, the color of the light generally will not be natural like that of incandescent lamps, and the color rendering of the objects illuminated by the light in general will not be natural. However, discharge lamps with additives have been developed that perform well in this respect.

8. Most discharge lamps have a much greater light output than is required for dwellings in developing countries. The following is a short survey of the most widely used types of small lamps:

(a) Low pressure sodium lamps emit monochromatic light almost exclusively. The color appearance of this light is not considered unpleasant, but it has no color rendering quality. As a result, the colors of objects appear in tones of yellow and brown, making this type of lamp unsuitable for domestic indoor applications. In domestic lighting it can be used for security lighting around dwellings. Its monochromatic character improves its visual acuity and its yellow color reduces glare better than any other light; the smallest available lamp is the 18 Watt/1,800 lm lamp with a system efficiency of 80 lm/W;

(b) High pressure sodium lamps emit yellowish light (correlated color temperature 2,100 K) and have a color rendering index Ra = 20; the smallest available type is a 50 Watt/3,300 lm lamp with a system efficiency of 53 lm/W; recently special lamps have been developed with better color rendering;

(c) High pressure mercury lamps emit cold bluish light (correlated color temperature 6,000 K) and have a color rendering index Ra = 16; the smallest type is 80 Watt/3,500 lm and a system efficiency of 35 lm/W;

(d) Colorcorrected high-pressure mercury vapor lamps are high pressure mercury vapor lamps with coated phosphors that transform the ultra violet radiation of the mercury discharge into visible radiation. The smallest available type is a 50 Watt/2,000 lm lamp with a system efficiency of 32 lm/W. The color appeareance of the light is white (correlated color temperature 3,400 K) and the colorendering index Ra = 52;

(e) Blended light lamps are color corrected high-pressure mercury vapor lamps with a built-in filament that is used as ballast; the efficiency of the smaller ones has the same order of magnitude as an incandescent lamp: a 100 Watt/1,100 lm lamp has a system efficiency of 11 lm/W.

Fluorescent Lamps

9. Fluorescent lamps are low pressure mercury vapor lamps coated with phosphors. They are available in a wide variety of sizes, shapes and light colors. They represent the most widely used lamps for interior lighting in general. Their application in dwellings has mainly been restricted to the lighting of kitchens, bathrooms, garages, and other work areas. One reason these lamps may not have been used for general ambient lighting in homes could be the poor color rendering of conventional fluorescent lamps used in industries and offices for purely economic reasons. These long fluorescent tubes were unappealing to individuals who were not concerned with the cost savings from cheap electricity prices. After the energy crisis, fluorescent lamps were developed with better shapes to fit into residential homes. These are known as compact fluorescent lamps. These lamps are available in colors similar to those of incandescent lamps and have a similar color rendering quality. Since these compact lamps were first produced, they have become more widely accepted, although their higher price still represents an initial barrier despite the savings they will generate during their lifetimes.

10. Compact lamps are available in different shapes. Those that have been developed to facilitate the introduction of fluorescent lamps

for domestic lighting have built-in control gear and are single ended; these resemble SL lamps and simply replace incandescent lamps. Compact lamps that have seperate control gear -- the PL types that have two small, short tubes -- have been developed mainly for application in luminaires, where the luminaire manufacturer takes care of incorporating the control gear. The PLC type has four of these tubes, or two PL lamps joined together to form one single ended lamp to further reduce the lamp length. Compact lamps recently have been put on the market with built-in electronic control gear and a normal lamp base -- the PLC*E type.

11. Other fluorescent lamps included for comparison are the normal fluorescent lamps of tubular form. These are the smaller types within the range: the miniature lamps have a tube diameter of 15 mm and are designated as TL, whereas the TLD lamps have a diameter of 26 mm. Special lamps are developed for operation on electronic gear and are designated as TLDHF lamps, where HF stands for High Frequency because the mains frequency is converted from 50 or 60 Hz to 20 kHz or higher to obtain a higher efficiency. These lamp types have luminous efficacies of 90 lm/W, which means that the smallest type of 16 W has a similar output as two standard lamps, each of 60 W. This is included only for reasons of type completeness; its light output is too high compared to the standard and its economic performance is quite poor, particularly in the lower power region. For professional applications, where higher values of lumious flux are required and lamps are burned for more hours per year, these high frequency lamps are economically quite viable. The HF fluorescent lamps have the additional advantages of simple light output regulation and lower stroboscopic effects compared to incandescent lamps.

Lamp Characteristics as a Function of Mains Voltage Deviations

12. Variations in luminous flux, consumed power, and luminous efficacy are presented in the following three tables as a fuction of a changing mains voltage. Diagrams of these results are given in Part I (see Diagrams 1 - 3). These results can be summarized as follows: fluorescent lamps show less variations in energy efficiency, power consumption and luminous flux caused by variations in the power supply.

Table A2.1: VARIATIONS OF EMITTED LUMINO , FLUX
DUE TO DEVIATIONS OF THE POWER SUPPLY
(percentage of rated flux)

Voltage Change (%)	80	85	90	95	100	105	110	115	120
Incandescent	46	57	69	84	100	119	140	163	189
Halogen Inc.	51	61	72	85	100	116	134	153	175
SL* 9W			84	93	100	105	100		
SL* 13W			83	92	100	107	112		
SL* 18W			87	94	100	105	108		
PL* 5W -> 11W	83	89	93	97	100	105	107	111	114
PLC 10W		86	91	95	100	104	108	112	
PLC 13W		78	86	93	100	105	110	113	
Fluorescent		76	85	93	100	106	112	118	
PL* 5W -> 11W CAP		93	95	98	100	101	102	104	
PLC 10W CAP		93	95	98	100	102	103	105	
PLC 13W CAP		92	95	97	100	102	104	106	
Fluorescent CAP		92	95	98	100	103	105	106	

CAP refers to capacitor, which is included in the ballast.

Table A2.2: VARIATIONS OF POWER CONSUMPTION
DUE TO DEVIATIONS OF THE POWER SUPPLY
(percentage of rated power consumption)

Voltage Change (%)	80	85	90	95	100	105	110	115	120
Incandescent	70	77	84	92	100	108	116	125	134
Halogen Inc.	70	77	84	92	100	108	116	125	134
SL* 9W			80	90	100	112	123		
SL* 13W			76	87	100	109	120		
SL* 18W			78	87	100	115	130		
PL* 5W -> 11W	81	87	92	96	100	106	110	115	120
PLC 10W		83	88	94	100	105	111	118	
PLC 13W		77	85	93	100	106	112	118	
Fluorescent		74	83	92	100	107	115	123	
PL* 5W -> 11W CAP		91	94	97	100	102	105	107	
PLC 10W CAP		91	94	97	100	102	105	107	
PLC 13W CAP		91	94	97	100	102	105	107	
Fluorescent CAP		90	93	97	100	103	106	108	

CAP refers to capacitor, which is included in the ballast.

Table A2.3: VARIATIONS OF LUMINOUS EFFICACY
DUE TO DEVIATIONS OF THE POWER SUPPLY
(percentage of rated luminous efficacy)

Voltage Change (%)	80	85	90	95	100	105	110	115	120
Incandescent	65	73	82	91	100	110	120	130	141
Halogen Inc.	73	79	86	93	100	107	115	122	130
SL* 9W			108	105	100	95	83		
SL* 13W			108	105	100	96	89		
SL* 18W			110	107	100	95	86		
PL* 5W -> 11W	102	102	101	101	100	99	97	96	95
PLC 10W		104	102	101	100	99	97	94	
PLC 13W		101	101	100	100	99	98	96	
Fluorescent		103	103	102	100	100	97	97	
PL* 5W - 11W CAP		102	101	100	100	99	99	99	
PLC 10W CAP		102	101	101	100	99	99	99	
PLC 13W CAP		102	102	100	100	99	99	99	
Fluorescent CAP		102	102	101	100	99	99	98	

CAP refers to capacitor, which is included in the ballast.

Parameters for Major Lamp Types

Table A2.4 presents an overview of the major lamp parameters for the various types of lamps, and numerical values for ranges representing these parameters under 'normal' conditions.

Table A2.4: LAMP PARAMETERS

		Power range (W)	Luminous Flux range (lm)	Luminous Efficiency range (lm/W)	Colour Temperature range (K)	Colour Rendering range (Ra)	Lamp Life range (hrs)
General	lo	10	50	5	2500	100	100
Incandescent	hi	1500	35000	25	3000		2000
Tungsten	lo	10	150	15	2800	100	50
Halogen	hi	2000	60000	30	3300		2000
Standard	lo	4	150	40	2500	60	10000
Fluorescent	hi	200	13000	100	6500	95	20000
Compact	lo	5	250	50	2500	80	5000
Fluorescent	hi	25	1500	80	6500	90	10000
High Pressure	lo	50	1500	30	3000	25	10000
Mercury	hi	1000	60000	60	6000	60	20000
Blended H.P.	lo	100	1000	10	3000	40	5000
Mercury	hi	1250	40000	30	6000	50	10000
Metal Halide	lo	30	1500	50	3500	50	2000
	hi	2000	250000	125	6500	85	10000
High Pressure	lo	30	1500	50	2000	20	10000
Sodium	hi	1000	150000	150	2500	80	25000
Low Pressure	lo	15	1500	100	1700	--	10000
Sodium	hi	200	35000	200			15000

13. Table A2.5 gives an overview of the different lamp types and their general application area.

Table A2.5: OVERVIEW OF LAMP TYPES AND APPLICATIONS

	GI	TH	SFI	CFI	HPM	MH	HPS	LPS
Homes	x	x	x	x				
Offices			x	x		x	x	
General shops	x		x	x	x	x		
Display shops	x	x				x	x	
Studio theaters	x	x				x		
Indoor sports			x		x	x	x	
Industries			x		x	x	x	
Horticulture			x		x	x	x	x
Highways					x		x	x
Streets					x		x	x
Residential areas			x	x	x		x	x
Domestic security	x			x	x			x
Professional security					x		x	x
Outdoor sports						x		
Flood lighting		x				x	x	
Tunnels			x				x	x

GI - General Incandescent Lamps,
TH - Tungsten Halogen Lamps,
SFI - Standard Fluorescent Lamps,
CFI - Compact Fluorescent Lamps,
HPM - High Pressure Mercury Lamps, and
Blended H.P. Mercury Lamps,
MH - Metal Halide Lamps,
HPS - High Pressure Sodium Lamps and
LPS - Low Pressure Sodium Lamps

The Standard Lamp

14. Table A2.6 shows the performance of a standard lamp when fixed in different types of luminaires. Illuminances at the table-top are given in the second column. Illuminances at a horizontal plane at table height averaged over the entire room are given in the third column. The source luminances at a 75% angle and with the downward vertical that must be used in this case to test the glare are given in the fourth column, and the maximum permissible luminances on the same line in the fifth column. The different values of the limiting luminances are due to the vertical luminous surfaces which require lower luminances than horizontal luminous surfaces. In the last column the light output ratios of the luminaires are given.

Table A2.6: ILLUMINANCES AND LUMINANCE FOR 60 W LAMP IN DIFFERENT LUMINAIRES

	Illuminance (lx)		Luminance (cd/m)		Light
		Average	Source	Glare	Output
	At Table	Horizontal	75°	Limit	Ratio
Bare lamp	32	20	20,000	2,000	1.00
Lamp with reflector	75	25	3,000	9,000	0.70
Lamp with spherical	26	16	3,000	2,000	0.80
Diffusor lamp with					
Shielding cylinder	50	22	3,000	9,000	0.80

15. The table shows that the use of a bare lamp is not a good practice because of the glare experienced by users of the room that have the lamp in their visual field (the lamp's luminance is ten times too high). Moreover, its performance in producing illuminances at the task area is not good enough. Thus, the use of a bare lamp should be excluded as a reference for comparison because of the severe glare that it causes for users with the source in their field of view. The use of the lamp in an opal globe (spherical diffusor) can reduce the glare substantially. If a larger globe or other shaped diffusor of sufficient size is used, the recommended glare control will be achieved. The luminance limit for glare control is higher if the vertical projection of the luminous area is zero. Glare control requirements, therefore, can more easily be met with luminaires that emit from horizontal planes only. Both the reflector and the shielding cylinder are constructed so that the lamp is sufficiently shielded from view: above 70° with the downward vertical for lamps with luminances lower than 20,000 cd/m^2, and above 60° for higher lamp luminances.

16. The above glare limits essentially refer to higher illuminances: 150 to 300 lux. For the lower illuminances it will be sufficient to use shielding angles as a criterion for glare control; the shielding of the lamp from view by the luminaire should be at an angle with the horizontal viewing direction of 20° or more for lamps with luminances below or equal 20,000 cd/m^2 and of 30° or more for lamps of higher luminances. The chromaticity coordinates x = 0.46; y = 0.41 are almost equal to those of a black-body radiator of 2750° K, which means that it is perceived as a natural white source, with an excellent colour rendering quality (R_a equals 100). The CIE Guide on Interior Lighting recommends an index R_a greater than or equal to 80 for domestic purposes.

Table A2.7: EQUIPMENT COSTS OF ELECTRIC LAMPS

Lamp Model	Price Lamp + ballast $
TL 8W/29	3.55 + 8.60
TL 8W/82	4.90 + 8.60
PL 9W	10.33 + 6.23
PL 9W DC	10.33 + 54.00
PLC 10W	15.83 + 6.77
PLC *11E	30.71 +
SL*13	18.48
GLS 40W	0.93
GLS 60W a/	0.93
GLS 75W	1.00
SL*18	18.95
PL 11W	11.76 + 6.23
PL 11W DC	11.76 + 54.00
PLC 13W	16.79 + 6.77
PLC*15E	33.10
TL 13W/33	3.62 + 8.60
TL 13W/82	5.40 + 8.60
TLD 15W	5.12 + 11.62
TLDHF 16W	6.61 + 54.29

Original prices in HFl were converted to US$ at DFL2.1/$.

J..

ANNEX 3

Non-Electric Light Production

1. The production of light by the available non-electric light sources is based on the principle of incandescence: when heated to a high temperature, a substance emits visible radiation according to its high temperature and its spectral emissivity. Of the available sources, two categories can be distinguished: those with carbon incandescence and those with incadescence of rare earths.

Carbon Incandescence

2. In the case of carbon incandescence, the light is produced by carbon particles heated in a flame such as the flame of burning wood or gas, the flames of wicks which burn up hydrocarbons, as in wick or oil lamps. Because the spectral emissivity of carbon is largely independent of the wavelength, carbon is a so called "gray" radiator (like tungsten used in the filaments of electric incandescent lamps). As a consequence, the spectral composition of the light emitted by carbon incandescence is similar to that of a black-body radiator with a slightly different temperature. In practice, this means that the light has a "natural" color and "natural" color rendering of objects illuminated by that light.

Rare Earths Incandescence

3. Rare earths incandescence occurs when a Welsbach mantle is placed over a flame and heated to incandescence. The rare earths (mainly Cerium, Thorium, and Lanthanum) have emissivities that are selective with regard to the wavelengths. As a consequence, the spectral composition of the light from an incandescent Welsbach mantle differs from that of a black-body. As a practical consequence, the color of the light as well as its colour rendering are unnatural (greenish). However, the reason for using incandescent mantles over gas flames is to obtain a higher temperature, which results in more visible radiation being emitted at the same fuel consumption as in the case of carbon incandescence. Carbon incandescence in the flame should be prevented; this can be achieved by a careful control of the flow, pressure, and mixture of the currents of air and gas. Especially when liquid fuels are used, rather complex constructions are necessary for preheating and pressurizing.

Different Types of Lamps

Wax Candle

4. The luminous flux of most commonly-used ordinary candles is on the order of 10 lumens. These candles are seldom used for general lighting in homes but they may find application for other purposes, such

as religions meetings and ceremonies. Other types of candles may be used for orientation lighting; these include a Waxine light, which is a candle in a glass cylinder (also referred to as the Hindenburger lamp because of its use in the trenches during World War I). It has a much lower light output -- approximately 2 lumen -- but it also has a much lower fuel consumption than the ordinary candle. The combustion heat of the wax candle and the Waxine light in this study was taken as the average of stearic-acid and palmatic acid; no great changes are expected when altering the proportions of the two components.

Calcium Carbide

Carbide lamps are available in a range of luminous fluxes but are rather obsolete nowadays in Western European countries. The one used in this study had a soapstone burner without a mantle. Because of its offensive smell, this type usually will not be used for general lighting in living rooms, and its application normally will be restricted to outdoor lighting, where its relative insensitivity to air currents is of maximum benefit. The process for the formation of acetylene and hydrated lime from water and calcium carbide is described by the following expression:

$$CaC_2 + 2H_2O = C_2H_2 + Ca(OH)_2;$$

Theoretically 64.1 grams of carbide and 36 grams of water produce 26 grams of acetylene and 74.1 g hydrated lime. In practice, about 25% more of the raw carbide was required to produce 26 g acetylene. For the calculations it was assumed that no carbide was present in the resiuum when the flame was extinguished because no smell of carbide reacting with water could be detected upon opening the generator. Since no information was available on the chemical composition of the impurities in the carbide, it cannot be determined if gaseous by-products were formed during the chemical rection which may have added to the reduction in weight.

Kerosene Wick

5. Kerosene wick lamps have been manufactured in a great variety of types and sizes. Nowadays the hurricane lamp is the most widely used; most other types have become obsolete in Western European countries. For this study, a Matador burner was selected over a hurricane lamp because the latter screens out too much light in quite a few directions. This would make it difficult to compare with lamps that freely radiate at all azimuth angles. In order for the kerosene wick lamp to operate at its maximum light output without forming soot the wick must be sharply cut in a plane parallel to the upper plane of the cones between which the wick is positioned. Changing the height of the wick also changes its ideal form. Especially a tiny raveling at the top of the wick already gives rise to a peak in the flame and related soot formation. Both facts prevent the lamp from generating maximum light output in a simple way when the formation of soot either at the glass cylinder or in the room is not allowed. The deposit of soot at the glass cylinder reduces the light output of the lamp considerably.

Kerosene Welsbach Mantle

6. Pressurized kerosene lamps with a gas generator and Welsbach mantle are available in various sizes. One of these lamps in the middle of the range was chosen because it is the type most commonly used and to avoid generating too high a thermal load in the photometric sphere. Operating the pressurized kerosene lamp with Welsbach mantle requires some training, particularly because pre-heating and igniting the lamp may cause soot to be deposited at the mantle and which can result in a reduction of efficiency. Also, the light output is not constant over time. While starting up, the light output increases relatively rapidly to a maximum, after which the light output gradually reduces which means that the pump must be used to restore the pressure of the lamp about every half hour.

Gasoline Welsbach Mantle

7. This lamp is similar to the Kerosene Welsbach Mantle but is less commonly used, mainly because of its fire risk. The gasoline lamp selected for this study belongs to the middle of the range of available lamps. It does not require preheating, which makes it easier to operate. However it does require pumping at regular intervals to restore the pressure if the light output is to be maintained at a given level.

Gas

8. The most widely used gases for lamps are propane and butane which are delivered in cylinders, and through the gas supplied by gas mains: natural gas, town gas, biogas, etc. Nowadays gas lamps always use a Welsbach mantle. For practical reasons no propane lamp was chosen for this study because the scales used to weigh the fuel consumption did not accommodate the mass of a propane lamp. The butane lamp selected had a dispensable cartridge (Camping Gaz). The butane lamp operating on gas from a cartridge with about 200 grams of gas, gradually decreased its light output due to the heat of evaporation distracted from the cartridge. This reduces gas pressure and fuel consumption.

9. The test results of the measurements carried out for this study are summarized in Table A3.1:

Table A3.1: RESULTS MEASUREMENTS

	(lm)	chromaticity x/y coord.	CCT (K)	color rendering	consump. rate g/h	power rating (W)	energy efficiency (lm/W)	fuel cons. (kg/klmh)	cal. value fuel (MJ/kg)
Waxine light	1 - 3				2 - 3	27	0.07	1.3	39.6
Candle	11 - 16	.530/.412	1970	excellent	5.5- 7.2	70	0.2	0.5	36.0
Kerosene wick	40 - 50	.511/.417	2160	excellent	34 - 39	460	0.1	0.8	45.0
Carbide	50 - 250	.498/.415	2320	excellent	6 - 23	86	0.7	0.25	20.6
Butane	330 - 500	.478/.433	3030	poor	28 - 34	415	1.0	0.075	48.0
Kerosene mantle	220 - 560	.460/.432	2830	poor	45 - 55	625	0.8	0.1	45.0
Gas mantle	300 - 700	.463/.426	2760	poor	25 - 35	360	1.2	0.07	42.9

Table A3.2: EQUIPMENT COSTS OF NON-ELECTRIC LAMPS

	Fuel Price ($/kg)	Spec. Fuel Costs ($/klmh)	Price of Lamps ($)	Life of Lamp (hours)
Kerosene wick lamp	0.40	0.33	3.5	4500
Carbide lamp	9.50	2.38	4.5	1500
Butane lamp	0.81	0.062	20	7500
Kerosene mantle lamp	0.40	0.040	25	7500
Gasoline mantle lamp	0.90	0.062	25	7500
60 W reference lamp	0.10 a/	0.008	0.93	1000

a/ Per kWh.

Summary of Results

10. The stability of the lamps was much weaker than that of electric lamps, not only over longer periods but also during the short periods when they were placed in the Ulbricht sphere. Non-electric lamps have to be regulated to provide a roughly constant light output. Consequently, the luminous flux readings have an accuracy of no more greater than about 10 percent. By comparing the energy efficiencies of lamps operating at their maximum light output with those operating at a much lower output, comparing the different output levels, it is clear that greater output, allows a higher efficiency. This can be explained by the reduced light outputs associated with lower temperature. However, no significant differences in correlated color temperature could be measured when comparing the different output levels.

ANNEX 4

Prices and Costs as found in Practice

The following data were collected in Rwanda and Burundi during the micro survey in October 1987 and form the basis for the first example analyzed in Chapter 4.

Kerosene wick lamps
equipment costs: $5.8
estimated lifetime: 10 year
daily use: 5.0 hrs
light output: 47.5 lm
kerosene consumption: 0.115 l/day
other costs (wicks, glass cover): $0.12/month

Kerosene mantle lamps
equipment costs: $19.8
estimated lifetime: 5 year
daily use: 5.0 hrs
light output: 400 lm
kerosene consumption: 0.21 l/day
other costs: $0.13/month

Electric lamps, electricity grid
incandescent lamp (40 or 60W): $0.83
fluorescent lamp 40 W: $2.1; lifetime: 5 year
,, fixture $10.0; lifetime: 25 year
connection charge, wiring etc.: $1150, spread out evenly over 25 years
average 4 incandescent lamps (2*40 W; 2* 60W) used for 5 hours/day and 2 fluorescent lamps (40 W) used for 13 hours/day

Electric lamps, battery operated
fluorescent lamp 20 W, 12 V used: 5.0 hours/day
equipment costs: $26.6 (lamp, fixture, ballast, cables, etc.) lifetime: 5 years
battery 36 AH, 12 V: $107, lifetime: 5 year
recharging: once every 12 - 16 days, costing: $2.7 every time

ANNEX 5

Literature

1. The following publications may be used as reference sources for information on interior lighting practices and measurement standards.

(a) Guide on Interior Lighting
Publication CIE no. 29.2 (1986)
The international guide on interior lighting is designed to be used by countries that want to introduce or update their national lighting recommendations; the guide can also be used by enumerators in countries which do not yet have national recommendations.

(b) Methods of characterizing Illuminance meters and Luminance meters
Draft Technical Report CIE TC 2.2 (1984)
Gives performance, characteristics, and specifications

(c) Report of Working Group II of TC 7.02 of the CIE (1987)
State of the art report on light sources and control gear.

(d) Handbuch der Lichttechnik, R Sewig
Berlin (1938), Verlag von Julius Springer
Chapters B.11 and B.12, by Alberts.
Gives information on non-electric light sources, their principles and applications.

(e) Calculations for Interior Lighting
Basic Method, Publication CIE No. 40 (1978)
Gives the basic formulas for determining the relationship between the average room surface illuminances and the luminous flux distribution of the sources of the lighting installation. These are presented as a function of the room dimensions, room surface reflectances, and location of the light sources in the room.

(f) Calculations for Interior Lighting
Applied Method, Publication CIE No. 52 (1982)
Gives tables for practical installation designs or verification and classification of flux distributions of sources to enable fast pre-determination of applications.

(g) International Lighting Vocabulary
Publication CIE NO. 17.4 (1987)
A dictionary of international terms for electric and non-electric lighting sources.

PPR Working Paper Series

	Title	Author	Date	Contact
WPS30	The Adding Up Problem	Bela Balassa	July 1988	N. Campbell 33769
WPS31	Public Finance and Economic Development	Bela Balassa	August 1988	N. Campbell 33769
WPS32	Municipal Development Funds and Intermediaries	Kenneth Davey	July 1988	R. Blade-Charest 33754
WPS33	Fiscal Policy in Commodity-Exporting LDCs	John Cuddington	July 1988	R. Blade-Charest 33754
WPS34	Fiscal Issues in Macroeconomic Stabilization	Lance Taylor	September 1988	R. Blade-Charest 33754
WPS35	Improving the Allocation and Management of Public Spending	Stephen Lister	August 1988	R. Blade-Charest 33754
WPS36	Means and Implications of Social Security Finance in Developing Countries	Douglas J. Puffert	August 1988	R. Blade-Charest 33754
WPS37	Black Market Premia, Exchange Rate Unification and Inflation in Sub-Saharan Africa	Brian Pinto	July 1988	R. Blade-Charest 33754
WPS38	Intergovernmental Grants in Developing Countries	Larry Schroeder	September 1988	R. Blade-Charest 33754
WPS39	Fiscal Policy in Low-Income Africa	Stephen A. O'Connell	July 1988	R. Blade-Charest 33754
WPS40	Financial Deregulation and the Globalization of Capital Markets	Eugene L. Versluysen	August 1988	R. Blade-Charest 33754
WPS41	Urban Property Taxation in Developing Countries	William Dillinger	August 1988	R. Blade-Charest 33754

PPR Working Paper Series

	Title	Author	Date	Contact
WPS42	Government Pay and Employment Policies and Government Performance in Developing Economies	David L. Lindauer	August 1988	R. Blade-Cha 33754
WPS43	Tax Administration in Developing Countries: Strategies and Tools of Implementation	Tax Administration Division		
WPS44	The Size and Growth of Government Expenditures	David L. Lindauer	September 1988	R. Blade-Cha 33754
WPS45-WPS60	Assigned to WDR			
WPS61	Student Performance and Schools Costs in the Philippines' High Schools	Emmanuel Jimenez Vicente Paqueo Ma. Lourdes de Vera	August 1988	T. Hawkins 33678
WPS62	Universities in Arab Countries	George I. Za'rour	September 1988	C. Christoba 33640
WPS63	Does Japan Import Less Than It Should?	Kenji Takeuchi	July 1988	J. Epps 33710
WPS64	Cocoa and Coffee Pricing Policies in Cote d'Ivoire	Takamasa Akiyama	August 1988	D. Gustafson 33714
WPS65	Interaction of Infant Mortality and Fertility and the Effectiveness of Health and Family Planning Programs	Howard Barnum	July 1988	S. Ainsworth 31091
WPS66	Slowing the Stork: Better Health for Women through Family Planning	Anthony R. Measham Roger W. Rochat	July 1988	A. Manciano 33226
WPS67	Price and Tax Policy for Semi-Subsistence Agriculture in Ethiopia	Robert D. Weaver Saad Ali Shire	August 1988	D. Gustafsor 33714
WPS68	Domestic Lighting	Robert van der Plas	October 1988	V. Burroughs 33635